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2011 ESTCP Live Site Demonstrations Marysville, CA

ESTCP MR-1165 Demonstration Data Report Former Camp Beale TEMTADS MP 2×2 Cart Survey

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14. ABSTRACT
The TEMTADS Man-Portable 2×2 sensor array was demonstrated at the former Camp Beale, CA during June 2011 as part of the ESTCP Live Site Demonstrations. New TEM sensors which replace the vertical-axis receive coils with triaxial receivers were used. Adding the horizontal receiver components improves the localization of the target. This system was designed to be deployable in areas inaccessible to vehicle-towed arrays. Data are collected at each target location while the cart is stopped, with an on-target collection time of approximately 1 minute. The data are inverted to determine the principal axis eddy current decay functions of the targets. Classification is based on comparing the eddy current decay functions for each target with those of the various munitions targets of interest at the site, as well as a variety of clutter items that are representative of the non-hazardous metal debris at the site. We report the classification performance results with the TEM array for roughly 900 unknown targets at the former Camp Beale.

15. SUBJECT TERMS

Discrimination	Multi-sensor Towed Array Detection System (MTADS)	TEMTADS
Classification	Electromagnetic Induction (EMI)	Former Camp Beale, CA
Unexploded Ordnance (UXO)	Transient Electromagnetic Induction (TEM)	

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Acronyms

Abbreviation	Definition
AOL	Advanced Ordnance Locator
APG	Aberdeen Proving Ground
ASCII	American Standard Code for Information Interchange
ATC	Aberdeen Test Center
CRREL	Cold Regions Research and Engineering Laboratory
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
HASP	Health and Safety Plan
Hz	Hertz
IVS	Instrument Verification Strip
MP	Man-Portable
MR	Munitions Response
MTADS	Multi-sensor Towed Array Detection System
NRL	Naval Research Laboratory
PDA	Personal Data Assistant
POC	Point of Contact
QC	Quality Control
RMS	Root-Mean-Squared
RTK	Real Time Kinematic
Rx	Receiver
SAIC	Science Applications International Corporation
SLO	San Luis Obispo
SNR	Signal-to-Noise Ratio
TEM	Time-domain Electro-Magnetic
TEMTADS	Time-domain Electro-Magnetic MTADS
TOI	Target of Interest
Tx	Transmit(ter)
UXO	Unexploded Ordnance

1.0 INTRODUCTION

1.1 ORGANIZATION OF THIS DOCUMENT

This document serves as the demonstration data report for the Man-Portable Electromagnetic Induction (EMI) Array for UXO Detection and Discrimination, or TEMTADS MP 2x2 Cart, participation in the Environmental Security Technology Certification Program (ESTCP) Live Site Demonstrations at the former Camp Beale, located in Marysville, CA in June, 2011. To limit the repetition of information, demonstration- and site- specific information that is presented elsewhere, such as the ESTCP Live Site Demonstrations Plan [1] is noted and not repeated in this document.

1.2 STUDY BACKGROUND AND OBJECTIVES

Please refer to the ESTCP Live Site Demonstrations Plan [1].

1.3 SPECIFIC OBJECTIVES OF DEMONSTRATION

As part of NRL's ESTCP-funded Live Site Demonstrations, the Naval Research Laboratory (NRL) conducted a cued classification survey within the 50-acre former Camp Beale, CA Man-Portable (MP) demonstration site of 913 anomalies identified from a Geonics EM61-MK2 cart survey. This survey was conducted using the NRL TEMTADS MP 2x2 Cart with sensors upgraded to include triaxial receiver coils. Characterization of the system responses to the Targets of Interest (TOIs) was based on previously acquired TEMTADS reference data. These reference data have been collected at our facilities and as part of a number of demonstrations. See Section 5.4.1 for further details. All data were collected in accordance with the overall demonstration objectives and the demonstration plan.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 EMI Sensors

The EMI sensor used in the TEMTADS arrays is based on the Navy-funded Advanced Ordnance Locator (AOL), developed by G&G Sciences. The AOL consists of three orthogonal transmit coils arranged in a 1m cube. We have adopted the transmit (Tx) and receive (Rx) subsystems of this sensor directly, but with multiple 35 cm square sensors which can be assembled in a variety of array configurations. We also made minor modifications to the control and data acquisition computer to make it compatible with our deployment schemes.

A photograph of a standard TEMTADS sensor element (as used in the MR-200601 array) under construction is shown in the left panel of Figure 2-1. The transmit coil is wound around the

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outer portion of the form and is 35 cm on a side. The 25 cm square receive coil is wound around the inner part of the form which is re-inserted into the outer portion. An assembled sensor with the top and bottom caps used to locate the sensor in the array is shown in the right panel of Figure 2-1.

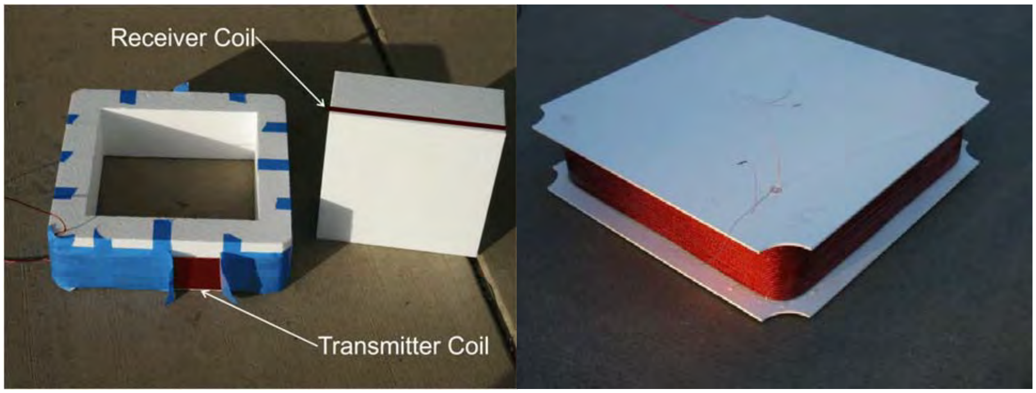

Figure 2-1 – Construction details of an individual standard TEMTADS EMI sensor (left panel) and the assembled sensor with end caps attached (right panel).

In addition to the TEMTADS 5x5 array developed under ESTCP MR-200601, the TEMTADS MP 2x2 Cart system was designed and built using the same sensor elements. After demonstration of the MP system at the APG Standardized UXO Test Site in August, 2010 [2], revision of the sensor technology was indicated for the MP system to collect sufficient data over an anomaly. A modified version of the sensor element was designed and built, replacing the single, vertical axis receiver coil of the original sensor with a three-axis receiver cube. These receiver cubes are identical in design to those used in the second-generation AOL and the Geometrics MetalMapper (ESTCP MR-200603) system with dimensions of 8 cm rather than 10 cm. The CRREL MPV2 system (ESTCP MR-201005) uses an array of five similar receiver cubes and a circular transmitter coil. The new sensor elements are designed to have the same form factor as the originals, aiding in system integration. A new coil under construction is shown in Figure 2-2.

Figure 2-2 – Individual updated TEMTADS EMI sensor with 3-axis receiver under construction.

Decay data are collected with a 500 kHz sample rate until 25 ms after turn off of the excitation pulse. This results in a raw decay of 12,500 points; too many to be used practically. These raw decay measurements are grouped into 122 logarithmically-spaced “gates” with center times ranging from 25 μs to 24.375 ms with 5% widths and are saved to disk.

2.1.2 Sensor Array

The TEMTADS MP 2x2 Cart array is comprised of four individual EMI sensors with 3-axis receivers, arranged in a 2 x 2 array as shown in Figure 2-3. The center-to-center distance is 40 cm yielding an 80 cm x 80 cm array. A picture of the array mounted on the TEMTADS MP 2x2 Cart platform is shown in Figure 2-4.

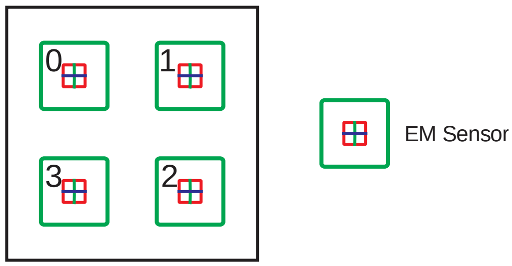

Figure 2-3 – Sketch of the EMI sensor array showing the position of the four sensors.

Figure 2-4 – TEMTADS MP 2x2 Cart sensor platform.

For each series of measurements with the array, we cycle through the sensors transmitting from each in turn. After each excitation pulse, we record the response of all twelve receive coils. Thus, there are 48 (4 x 4 x 3) transmit/receive pairs recorded. Figure 2-5 shows an example set of data for a shotput located in the former Camp Beale Instrument Verification Strip (IVS) centered under the array. See Section 5.4.3 for further discussion of the IVS. The 16 plots correspond to the 16 different transmit coil / receive cube pairings (reference Figure 2-3 for the sensor numbering), with each plot showing the measured signals for the three receiver axes.

Signal levels are in mV per Amp of transmit current (mV/A). The nominal transmit current is roughly 7.5 Amp.

The responses of a number of inert munitions items and simulants have been characterized with the completed array both mounted on a test stand and on our test field while mounted on the cart. As discussed in Section 5.4.1, a substantial library of response signatures for munitions, surrogates, and range scrap/clutter already exists for the TEMTADS Discrimination Array. These new measurements confirmed that the existing library can be used for anomaly classification using data from this array.

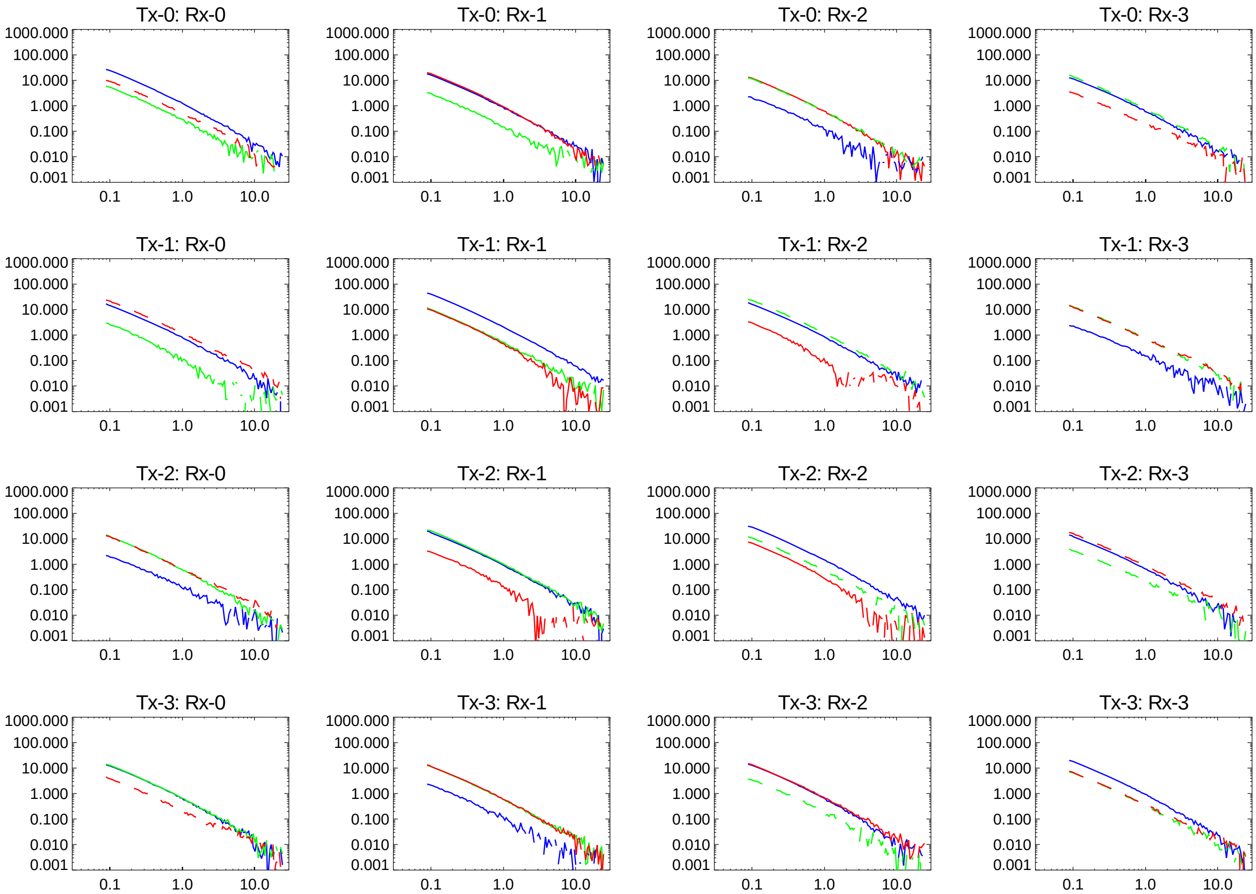

Figure 2-5 – The response of the individual sensors to IVS target T-001, a shotput located under the center of the array. The z,y,x-components in each subplot are shown in blue, green, and red, respectively. The dashed lines indicate a voltage of opposite sign as compared to the solid line of the same color.

2.1.3 Application of the Technology

For this demonstration, the anomaly list was derived from EM61-MK2 data collected in Spring, 2011 by Parsons. The anomalies were selected from Channel 2 (366 μsec time gate) data with a threshold of 5.2 mV. This threshold represents the expected response for a 37mm projectile in the least favorable orientation buried at a depth of 30 cm. Anomalies which were within 1m of each other were aggregated by the data analyst using a series of predetermined criteria. The anomaly list for this demonstration was provided by the ESTCP Program Office. The location of each anomaly from the list was re-acquired by others using RTK-GPS and marked in the field with a plastic pin flag prior to the demonstration, allowing the TEMTADS to be centered over each flag. Because this demonstration was conducted on sloping hillsides and under moderate tree coverage, each target position had been reacquired and the flag positions corrected for slope and positioning error related to the original EM61-MK2 survey by NAEVA Geophysics prior to our survey. When positioned over the target, the array sensors were fired sequentially, and decay data were collected from all twelve receiver coils for each excitation. These data were then stored electronically on the data acquisition computer. Prior to moving to the next target, the four monostatic, z-axis (vertical axis) signal amplitudes were evaluated for an early time gate (71 μs) and compared to a 'low SNR' threshold (nominally 5 mV/Amp). In the full TEMTADS 5x5 Discrimination Array, these data are background-subtracted and presented to the operator. This step provides the operator with the opportunity to reposition the array if the anomaly is not well centered under the array. The smaller footprint of the MP array and the additional data from the new multi-axis receiver cubes discussed in Section 2.1.4 complicates the interpretation and new interpretation procedures are in development. The data were transferred to the onsite data analyst several times each day for near real-time analysis at the demonstration site and to readily identify any potential data quality issues.

2.1.4 Development of the Technology

The TEMTADS MP 2x2 Cart is a man-portable four-element transient EMI system designed and built by the NRL with funding from ESTCP, to transition the time-domain EMI (TEM) sensor technology of the TEMTADS towed array (ESTCP Project MR-200601) to a more compact, man-portable configuration for use in more limiting terrain under project MR-200909. Like the towed array, this system is currently configured to operate in a cued mode, where the target location is already known. Decay data are collected until 25ms after turn off of the excitation pulse. These raw decay measurements are grouped into 122 logarithmically-spaced "gates". The TEMTADS MP 2x2 cart is shown in Figure 2-4.

Preliminary testing of the initial system configuration [3] found that for high SNR ($\geq$ 30) targets one measurement cycle provides enough information to support classification. For deeper and/or weaker targets, more robust estimates of target parameters are obtained by combining two closely spaced measurements. Two measurements per anomaly were typically made proactively to avoid the potential need to revisit a target a second time [3]. As part of project MR-200909, a demonstration was conducted to rigorously investigate the capabilities of this new sensor platform for UXO classification in a cued data collection mode at the APG Standardized UXO Test Site in August, 2010. Analysis is still ongoing, but preliminary results have been presented [4]. Those results indicated that the inversion performance of the system was not comparable to that of the full TEMTADS array for lower SNR targets due to the limits of the smaller data set (fewer looks at the target).

Revision of the sensor technology was indicated for the MP system to collect sufficient data over an anomaly. A modified version of the EMI sensor was designed and built, replacing the single, vertical axis receiver loop of the original coil with a three-axis receiver cube. These receiver cubes are identical in design to those used in the second generation AOL and the Geometrics MetalMapper (ESTCP MR-200603) system with dimensions of 8 cm rather than 10 cm. The CRREL MPV2 system (ESTCP MR-201005) uses an array of five 8 cm receiver cubes and a circular transmitter coil. The new sensor elements were designed to have the same form factor as the originals, aiding in system integration.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The TEMTADS array is designed to combine the data advantages of a gridded survey with the coverage efficiencies of a vehicular system. The TEMTADS MP 2x2 Cart is designed to offer similar production rates in difficult terrain and treed areas that the TEMTADS 5x5 array cannot access.

The array is 80 cm square and mounted on a man-portable cart. Terrain where the vegetation or topography interferes with passage of a cart of that size will not be amenable to the use of the system. The combination of the MR-200601 transmitter coil and the 8 cm receiver cube is a new combination and the performance of the current generation of solver algorithms is currently under evaluation, including solvers designed for classification in multiple-object scenarios such as SAIC’s multi-solver [5]. The performance of these solvers could affect the limiting anomaly density (anomalies/acre) that can be tolerated by the system.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstration are given in Table 3-1 as a basis for the evaluation of the performance and costs of the demonstrated technology. These objectives are for the technologies being demonstrated only. Overall project objectives are given in the overall demonstration plan generated by ESTCP. Since this is a classification technology, the performance objectives focus on the second step of the UXO survey problem; we assume that the anomalies from all targets of interest have been detected and have been included on the provided target list.

3.1 OBJECTIVE: SITE COVERAGE

A list of previously identified anomalies was provided by the Program Office. The expectation was to gather cued data with the TEMTADS MP 2x2 Cart over each anomaly.

3.1.1 Metric

Site coverage is defined as the fraction of anomalies on the target list that was surveyed by the TEMTADS MP 2x2 Cart. Exceptions were made for topology / vegetation interferences.

Table 3-1 – Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Quantitative Performance Objectives			
Site Coverage	Fraction of assigned anomalies interrogated	Survey results	100% as allowed for by topography / vegetation
IVS Results	System responds consistently to emplaced items	Twice Daily IVS data	≤ 15% RMS variation in β amplitudes and fit depth
Depth Accuracy	Standard deviation in depth for interrogated items	Ground truth from validation effort	ΔDepth < 5 cm σDepth < 10 cm
Production Rate	# of anomalies investigated each day	• Survey results • Log of field work	Average of 125 anomalies/day
Data Throughput	Throughput of data QC process	Log of analysis work	All data QC'ed on site and at pace with survey
Qualitative Performance Objective			
Reliability and Robustness	General Observations	Team feedback and recording of emergent problems	Field team has no issues to report

3.1.2 Data Requirements

The collected data were compared to the original anomaly list. Any interferences (*e.g.*, a misidentified cultural item such as a fence post) were noted in the field log book as they were observed by the field team.

3.1.3 Success Criteria

The objective is considered met if 100% of the assigned anomalies were surveyed with the exception of anomalies that cannot be accessed due to topography / vegetation interferences.

3.2 OBJECTIVE: INSTRUMENT VERIFICATION STRIP (IVS) RESULTS

This objective supports that the sensor system is in good working order and collecting physically valid data each day. The items emplaced in the IVS were surveyed twice daily. The amplitude of the derived response coefficients and fit depth for each emplaced item were compared to the running average of the demonstration for repeatability. If a corresponding reference response was available in our library, the quality of the match was evaluated as well. For example, did the fit parameters extracted from data collected over a shotput buried in the IVS correspond to those of a sphere at the correct depth?

3.2.1 Metric

The reproducibility of the measured response of the sensor system to the emplaced items defines this metric.

3.2.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients and fitted depth. If available, a reference set of derived response coefficients for the same object was used.

3.2.3 Success Criteria

The objective is considered met if the RMS amplitude variation of the derived response coefficients and fitted depths was less than 15% of the average recovered response coefficients.

3.3 OBJECTIVE: DEPTH ACCURACY

An important measure of how efficiently any required intrusive investigation will proceed is the accuracy of the predicted depth of the targets marked to be dug. Large depth errors lead to confusion among the UXO technicians assigned to the effort costing time and often lead to the removal of a small, shallow object when a larger, deeper object was the intended target.

3.3.1 Metric

The average offset and standard deviation of the predicted depths with respect to the ground truth are computed for the items which are selected for excavation during the validation phase of the study.

3.3.2 Data Requirements

The anomaly fit parameters and the ground truth results for the excavated items are required to determine the performance of the fitting routines in terms of the predicted depth accuracy.

3.3.3 Success Criteria

This objective is considered met if the average error in depth (ΔDepth) was less than 5 cm and the standard deviation (σDepth) was less than 10 cm.

3.4 OBJECTIVE: PRODUCTION RATE

This objective considers a major cost driver for the collection of high-density, high-quality geophysical data, the production rate. Increased data collection rates translate to fewer days needed on-site for the data collection effort.

3.4.1 Metric

This objective is considered met if the number of anomalies investigated per day met or exceeded the success criteria listed below without sacrificing data quality or compromising personnel health and safety. Note that evaluation of this metric does not distinguish between regular data collection and necessary recollections, or redos. On any geophysical survey, there is going to be a necessary level of redo data collections and these should be planned for.

3.4.2 Data Requirements

The metric was determined from the combination of the field logs and the survey results. The field logs record the amount of time per day spent acquiring the data and the survey results determine the number of anomalies investigated in that time period.

3.4.3 Success Criteria

This objective is considered met if the average production rate was at least 125 anomalies/day. This metric is site-specific and was based on our previous experience with this site and the sensor system. The success criteria may vary at other sites based on site-specific conditions.

3.5 OBJECTIVE: DATA THROUGHPUT

The collection of a complete, high-quality data set with the sensor platform is critical to the downstream success of the Live Site Demonstrations. This objective considers one of the key data quality issues, the ability of the data analysis workflow to support the data collection effort in a timely fashion. To maximize the efficient collection of high quality data, a series of standard data quality checks were conducted during and immediately after data collection on site. Data which passed the QC screen were then processed into archival data stores. Individual anomaly analyses were then conducted on those archival data stores. The data QC / preprocessing portion of the workflow must keep pace with the data collection effort for best performance.

3.5.1 Metric

The throughput of the data quality control workflow was at least as fast as the data collection process, providing real time feedback to the data collection team of any issues.

3.5.2 Data Requirements

The data analysts log books provide the necessary data for determining the success of this metric.

3.5.3 Success Criteria

This objective is considered met if all collected data were processed through the data quality control portion of the workflow in a timely fashion.

3.6 OBJECTIVE: RELIABILITY AND ROBUSTNESS

This objective represents an opportunity for all parties involved in the data collection process to provide feedback on areas where the process could be improved.

3.6.1 Data Requirements

Discussions with the entire field team and other observations were used.

4.0 SITE DESCRIPTION

Please refer to the ESTCP Live Site Demonstrations Plan [1].

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The demonstration was designed to be executed in two stages. The first stage was to characterize the response of the TEMTADS MP 2x2 Cart with respect to the items of interest and to the site specific geology. Characterization of the sensor response to the items of interest was conducted at our home facility using both test stand and test field measurements prior to deployment. The background response of the demonstration site, as measured by the TEMTADS MP 2x2 Cart, was characterized throughout data collection.

The second stage of the demonstration was a survey of the demonstration site using the TEMTADS MP 2x2 Cart. The array was positioned roughly over the center of each anomaly on the source anomaly list and a data set collected. Each data set was then inverted using the data analysis methodology discussed in Section 6.0, and estimated target parameters determined. The archive data were submitted to the Program Office after the completion of the demonstration.

The schedule of field testing activities is provided in Figure 5-1 as a Gantt chart.

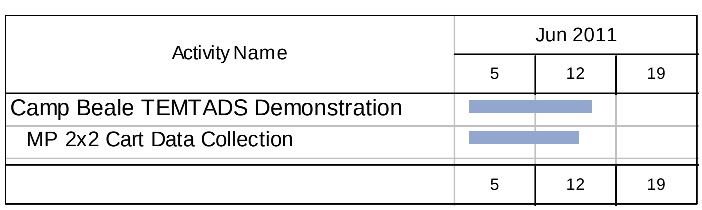

Figure 5-1 – Schedule of Field Testing Activities

5.2 SITE PREPARATION

Please refer to the ESTCP Live Site Demonstrations Plan [1].

5.3 SYSTEMS SPECIFICATION

This demonstration was conducted using the NRL TEMTADS MP 2x2 Cart.

5.3.1 TEMTADS MP 2x2 Cart

The TEMTADS MP 2x2 Cart was developed with support from ESTCP under project MR-200909. The cart, shown in Figure 2-4, is fabricated from PVC plastic and G-10 fiberglass.

5.3.2 Time-Domain Electromagnetic Sensor

The TEMTADS MP 2x2 Cart is a 2x2 square array of individual sensors. Each sensor has dimensions of 40 cm x 40 cm, for an array of 80 cm x 80 cm overall dimensions. The bottom of the array is positioned at a ride height of 20cm above the ground. The result is a cross-track and down-track separation of 40 cm. Sensor numbering is indicated in Figure 2-3. Each sensor consists of a 35 cm x 35 cm Tx coil and an 8 cm, 3-axis Rx cube. The transmitter electronics and the data acquisition computer are mounted in the operator backpack, as shown in Figure 5-2. Custom software written by NRL provides data acquisition functionality. After the array is positioned roughly centered over the center of the anomaly, the data acquisition cycle is initiated. Each transmitter is fired in a sequence. The received signal is recorded for all 12 Rx coils for each transmit cycle. The transmit pulse waveform duration is 16.2 s (0.9s block time, 9 repeats within a block, 18 blocks stacked, with a 50% duty cycle). While it is possible to record the entire decay transient at 500 MHz, we have found that binning the data into 122 time gates simplifies the analysis and provides additional signal averaging without significant loss of temporal resolution in the transient decays [6]. The data are recorded in a binary format as a single file with four data points (one data point per Tx cycle). The filename corresponds to the anomaly ID from the target list under investigation.

Figure 5-2 – TEMTADS 2x2 Electronics Backpack

5.3.3 Data Acquisition User Interface

The data acquisition computer is mounted on a backpack worn by one of the data acquisition operators. The second operator controls the data collection using a personal data assistant (PDA) which wirelessly (IEEE 802.11b) communicates with the data acquisition computer. The second operator also manages field notes and team orienteering functions.

Figure 5-3 – TEMTADS 2x2 MP Cart and Data Acquisition Operators

5.4 CALIBRATION ACTIVITIES

5.4.1 TEMTADS Sensor Calibration

For the TEMTADS family of sensors, a significant amount of data has been previously collected, both on test stands and under field conditions at our test field [7] and during our recent demonstrations at APG [4,8], SLO [9], Bridgeport, CT [4], and at the former Camp Butner [10]. These data and the corresponding fit parameters provide us with a set of reference parameters including those of clear background (i.e. no anomaly present).

Daily calibration efforts consisted of collecting background (no anomaly) data sets periodically throughout the day and signal data sets twice daily for each item in the IVS. The background (no anomaly) data sets are collected at quiet spots to monitor the system noise floor and for background subtraction of signal data. The items emplaced in the IVS are measured twice daily to monitor the repeatability of the system response. The amplitude of the derived response coefficients and fit depth for each emplaced item are compared to the running average of the demonstration for repeatability. RMS variations of less than 15% of the reference values are expected. If a corresponding reference response is available in our library, the quality of the match is evaluated as well.

5.4.2 Background Data

A group of anomaly-free areas throughout the demonstration site were identified in advance from the EM61-MK2 data set. The background locations were confirmed using an EM61-MK2 by the TEMTADS field team over the course of the demonstration. Since they all provided roughly comparable responses, a convenient subset of these locations was chosen to be visited periodically throughout each day of the demonstration. All 97 background measurements taken for the duration of the demonstration (June 6-15, 2011) are shown in Figure 5-4, and are presented as the mean and standard deviation of the four monostatic measured signals. Table 5-1 provides the intraday variations of the mean and standard deviation quantities of Figure 5-4.

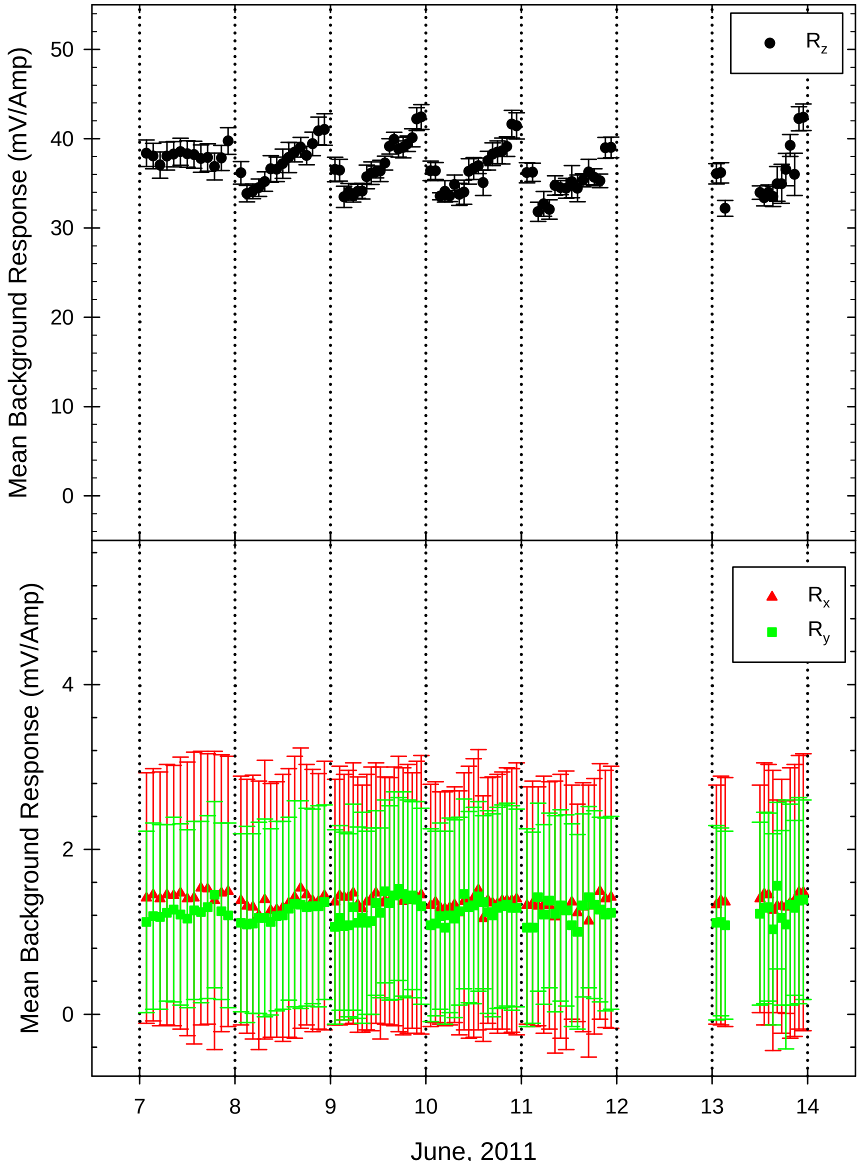

Figure 5-4 – Intra- and inter- daily variations in the response of the TEMTADS MP 2x2 array to background anomaly-free areas through the duration of the demonstration at the former Camp Beale. The upper panel plots the average measured signal of the four monostatic, Z-axis quantities, while the bars represent the standard deviation of those quantities (i.e. 1σ about the mean). The red and green points in the lower panel plot the average measured signal of the four monostatic, X- and Y-axis quantities, respectively.

Table 5-1 – Summary of the Daily Variation in the Mean and Standard Deviation of the Signals Measured for the Background Areas.

Date	# of Bkgs.	Mean Z (mV/Amp)	Std. Dev. Z (mV/Amp)	Mean Y (mV/Amp)	Std. Dev. Y (mV/Amp)	Mean X (mV/Amp)	Std. Dev. X (mV/A)
6/7/2011	13	38.07	1.49	1.24	1.10	1.45	1.64
6/8/2011	15	37.27	1.28	1.23	1.17	1.36	1.60
6/9/2011	20	37.26	1.03	1.28	1.16	1.40	1.57
6/10/2011	19	36.67	1.16	1.26	1.18	1.34	1.54
6/11/2011	16	35.18	1.14	1.24	1.15	1.31	1.53
6/13/2011	14	36.11	1.37	1.24	1.17	1.38	1.53

5.4.3 Instrument Verification Strip Data

The intent of the IVS was to provide the ability to verify the repeatability of the system response on several examples of items of interest. Details of the contents of the IVS are given in Table 5-2. Note that items T-003 and T-004 are reversed from the planned configuration given in the Program Office Demonstration Plan. Each emplaced item in the IVS was measured twice daily, once before starting the data collection process and a second time before shutting the system down at the end of each day.

Table 5-2 – Details of Former Camp Beale IVS

ID	Description	Easting (m)	Northing (m)	Depth (m)	Inclination	Orientation
T-001	Shotput	647,401.82	4,331,251.20	0.30	N/A	N/A
T-002	105mm HEAT Projectile	647,396.86	4,331,252.22	0.45	Horizontal	Across Track
T-003	60mm Mortar	647,387.21	4,3312,54.22	0.15	Horizontal	Across Track
T-004	37mm Projectile	647,392.08	4,331,253.17	0.15	Horizontal	Across Track
T-005	Small ISO	647,382.32	4,331,255.27	0.15	Horizontal	Across Track

All data sets for each of the emplaced IVS items were inverted using the data analysis methodology discussed in Section 6.0, and the estimated target parameters determined. As geolocation is not currently provided to the sensor system, only the variability in the inverted depth of each target was monitored. We summarize the results in the following Figures and Tables.

The derived response coefficients (β_1,β_2,β_3) for all 12 data sets taken over item T-001 of the IVS over the duration of the demonstration are plotted in the left panel of Figure 5-5. As expected, the amplitudes of the three coefficients are comparable in amplitude suggesting a spherical shape. Furthermore, upon examining the variation in the amplitude at 0.089 ms in the decay, it is observed (from right panel, Figure 5-5 and first entry in Table 5-3) that the RMS (σ) variation is less than 4% of the mean amplitude. Indeed, the observation can be made that apart from the β_2

and β_3 coefficients for item T-004, all RMS variations fall below 5% of the respective mean amplitudes. For item T-004, the transverse β coefficients, β_2 and β_3, are small (~0.10 mV/A), and the RMS variation is 8.3%, still in tolerance. Finally, it is important to note that for all items except T-001, the mean β amplitudes convincingly represent cylindrical shapes where β_2 and β_3 are comparable (equal within 5%) and smaller than β_1.

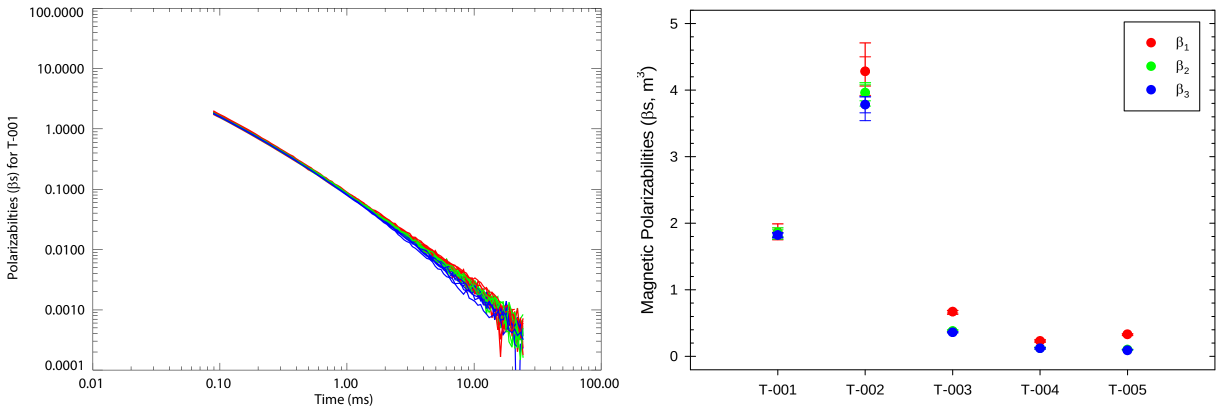

Figure 5-5 – Derived response coefficients for item T-001 emplaced in the IVS (left panel) and amplitude variations at 0.089 ms in the derived response coefficients for all items emplaced in the IVS (right panel). β_1 is in red; β_2 is in green; and β_3 is in blue.

Table 5-3 – Summary of the Amplitude Variations at 0.089 ms in the Derived Response Coefficients for All Items Emplaced in the IVS.

Item	β_1 Amplitude (m^3)				β_2 Amplitude (m^3)				β_3 Amplitude (m^3)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
T-001	1.75	1.99	1.86	0.07	1.76	1.93	1.85	0.05	1.78	1.86	1.82	0.03
T-002	3.92	4.71	4.28	0.22	3.76	4.11	3.96	0.12	3.54	3.90	3.78	0.12
T-003	0.63	0.69	0.67	0.02	0.36	0.40	0.38	0.01	0.35	0.37	0.36	0.01
T-004	0.21	0.25	0.23	0.01	0.11	0.14	0.12	0.01	0.11	0.13	0.12	0.01
T-005	0.31	0.34	0.33	0.01	0.09	0.11	0.10	0.00	0.09	0.10	0.09	0.00

The depth errors for all 12 data sets taken over item T-001 of the IVS over the duration of the demonstration are plotted in the left panel of Figure 5-6. The depth error is defined as the fit depth (or, equivalently, the inverted depth parameter) minus the ground truth depth given in Table 5-2. In a perfect world, these errors would contain as many negative results as positive ones, with the mean depth error for each item being close to zero. As Figure 5-6 (right) reveals, there appears to be a roughly -4 cm bias for all emplaced items except for item T-004. This indicates an offset in either the assumed sensor platform height or the burial depths. This will be investigated further. The RMS variation in inverted vs. reported depths for each emplaced IVS item were all below 1 cm. The statistics on depth error for each item are also provided in Table 5-4.

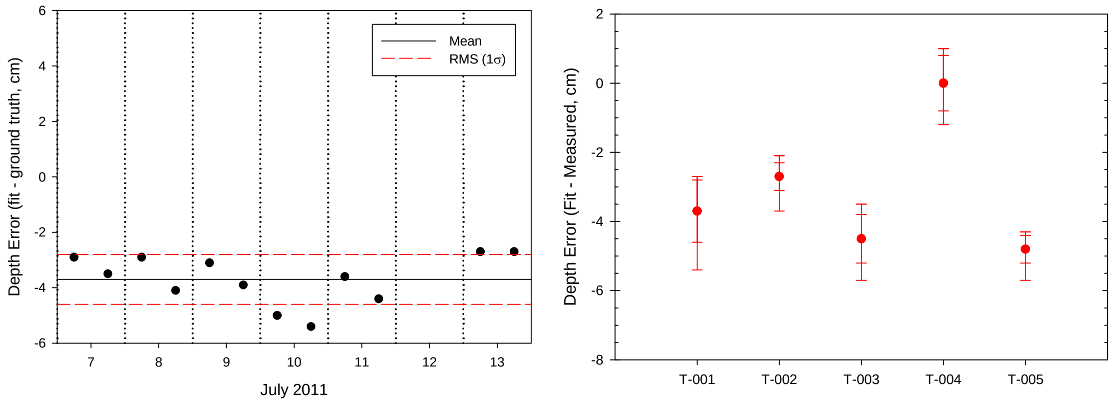

Figure 5-6 – Depth errors for item T-001 emplaced in the IVS (left panel) and depth error statistics for all items emplaced in the IVS (right panel).

Table 5-4 – Summary of Depth Error Statistics for all items emplaced in the IVS.

Item	Depth Error (cm)			
	Min	Max	Mean	RMS
T-001	-5.40	-2.70	-3.70	0.90
T-002	-3.70	-2.10	-2.70	0.40
T-003	-5.70	-3.50	-4.50	0.70
T-004	-1.20	1.00	0.00	0.80
T-005	-5.70	-4.30	-4.80	0.40

When a matching set of fit parameters is available in our library, the fitted parameters for the IVS items are compared to the library values to verify the physical validity of the results. Figure 5-7 show the fitted results for item T-001, the shotput, during the June 9, 2011 PM IVS run. The fitted results are shown in blue and the library values in red. The fit coherence was 0.98 and the fitted depth was 26 cm, indicating a good match to the library and a good depth fit excluding the -4 cm bias discussed above.

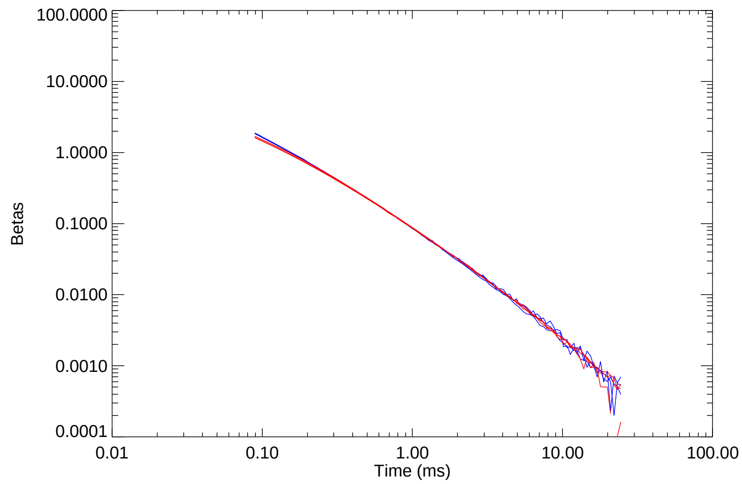

Figure 5-7 – Fitted magnetic polarizabilities (blue) for item T-001, the shotput, during the June 9, 2011 PM run of the IVS vs. library parameters for a 16-lbs steel shotput. The fit coherence was 0.98 and the fitted depth was 26 cm.

5.5 DATA COLLECTION PROCEDURES

5.5.1 Scale of Demonstration

A cued discrimination survey was conducted within the 50-acre Man-Portable area at the former Camp Beale of 913 previously-identified anomalies. The anomalies were selected from EM61-MK2 data previously collected, provided by the ESTCP Program Office, and were previously reacquired and flagged. This survey was conducted using the NRL TEMTADS MP 2x2 Cart. Performance of the system response was determined on a twice-daily basis using the onsite IVS. The data segment (chip) for each anomaly was analyzed, and fit parameters extracted. These results were provided to the ESTCP Program Office in addition to the archival data.

5.5.2 Sample Density

The EMI data spacing for the TEMTADS is fixed at 40 cm in both directions by the array design. One set of data was collected for each flag position as described in Section 5.3.2.

5.5.3 Quality Checks

Preventative maintenance inspections were conducted at least once a day by all team members, focusing particularly on the sensor cart and cabling. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios are available in the system spares inventory which was on site. Status on any break-downs / failures resulting in long-term delays in operations would have been reported immediately to the ESTCP Program Office.

Two data quality checks were performed on the EMI data. After background subtraction, the data from the 12 transmit/receive pairs were plotted as a function of time. An example plot is shown in Figure 5-8 for a horizontal 3-in diameter x 12-in long solid steel cylinder at a depth of 45 cm below the sensor array. The plots were visually inspected to verify that there was a well-defined anomaly without extraneous signals or dropouts. Further QC on the transmit/receive cross terms was based on the dipole inversion results. Our experience has been that data glitches show up as a degraded match of the extracted response coefficients to the reference values, when appropriate. This is quantitatively seen as a reduced fit coherence. The fit coherence is a value (0 – 1) reflecting how well the fit result response coefficients reproduce the collected data. Qualitative evaluation is also conducted by visual inspection of several QC plots by the data analyst.

Any data set deemed unsatisfactory by the data analyst was flagged and not processed further. The anomaly corresponding to the flagged data was logged for re-acquisition by the field team. Approximately 30 anomalies had to be recollected during this demonstration. A cable failure caused one receiver channel to become disconnected. This issue was caught during a routine download / QC cycle and the problem was limited to less than an hour. This demonstrates the value of conducted onsite data QC in providing near real-time feedback.

5.5.4 Data Handling

Data were stored electronically on the backpack data acquisition computer hard drive. Approximately every two hours, the field data were copied onto removable media and transferred to the onsite data analyst for QC/analysis. The data were moved onto the data analyst's computer and the media was recycled. Raw data and analysis results were backed up from the data analyst's computer to external hard disks daily. These results are archived on an internal file server at SAIC at the end of the survey. Examples of the TEMTADS file formats are provided in Appendix C. All field notes / activity logs were written in ink and stored in archival laboratory notebooks. These notebooks are archived at NRL and SAIC. Dr. Tom Bell is the POC for obtaining data and other information. His contact information is provided in Appendix B of this report.

5.6 VALIDATION

At the conclusion of data collection activities, all anomalies on the master anomaly list assembled by the Program Office will be excavated by Parsons. Each item encountered will be identified, photographed, its depth measured, its position recorded using cm-level GPS or a similar-capability technology (e.g. a robotic total station), and the item removed if possible. All non-hazardous items will be saved for later in-air measurements as appropriate. This ground truth information, once released, will be used to further validate the objectives listed in Section 7.0.

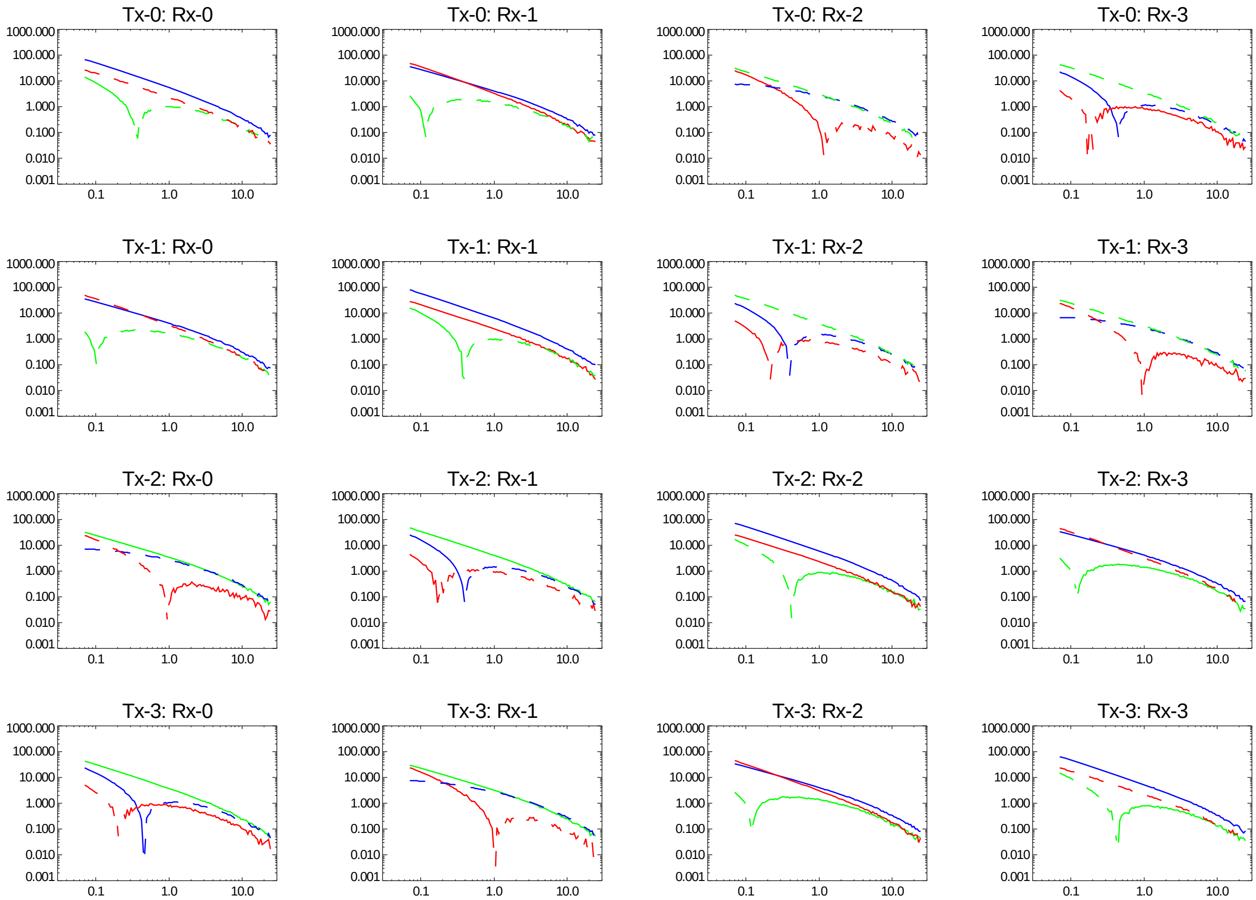

Figure 5-8 – QC Plot for a 3-in x 12-in solid steel cylinder, horizontal at a depth of 45 cm below the sensors. The z,y,x-components in each subplot are shown in blue, green, and red, respectively. The dashed lines indicate a voltage of opposite sign as compared to the solid line of the same color.

6.0 DATA ANALYSIS PLAN

6.1 PREPROCESSING

The TEMTADS array has four sensor elements, each comprised of a transmitter coil and a tri-axial receiver cube. For each transmit pulse, the responses at all of the receivers are recorded. This results in 48 possible transmitter / receiver combinations in the data set (4 transmitters x 4 receiver cubes x 3 receiver axes). Although the data acquisition system records the signal over 122 logarithmically-spaced time gates, the measured responses over the first 17 gates included distortions due to transmitter ringing and related artifacts and are discarded. We further subtract 0.028 ms from the nominal gate times to account for time delay due to effects of the receive coil and electronics [11]. The delay was determined empirically by comparing measured responses for test spheres with theory. This leaves 105 gates spaced logarithmically between 0.089 ms and 25.35 ms. In preprocessing, the recorded signals are normalized by the peak transmitter current to account for any variation in the transmitter output. On average, the peak transmitter current is approximately 7.5 Amps.

The background response is subtracted from each target measurement using data collected at a nearby target-free background location. The background measurements are reviewed for variability and to identify outliers, which may correspond to measurements over targets. In previous testing at our Blossom Point test field and during other demonstrations, significant background variability was not observed. It has been possible to use blank ground measurements from 100 meters away for background subtraction. Changes in moisture content and outside temperature have been shown to cause variation in the backgrounds, necessitating care when collecting data after weather events such as rain.

6.2 PARAMETER ESTIMATION

The raw signature data from the TEMTADS MP 2x2 Cart reflect details of the sensor/target geometry as well as inherent EMI response characteristics of the targets themselves. In order to separate out the intrinsic target response properties from sensor/target geometry effects, we invert the signature data to estimate principal axis magnetic polarizabilities for the targets. The TEMTADS data are inverted using the standard induced dipole response model wherein the effect of eddy currents set up in the target by the primary field is represented by a set of three orthogonal magnetic dipoles at the target location [12]. The measured signal is a linear function of the induced dipole moment **m**, which can be expressed in terms of a time dependent polarizability tensor $\mathbf{B}$ as

$$\mathbf{m} = \mathbf{U}\mathbf{B}\mathbf{U}^{T}\cdot\mathbf{H}_0$$

where $\mathbf{U}$ is the transformation matrix between the physical coordinate directions and the principal axes of the target and $\mathbf{H}_0$ is the primary field strength at the target. The eigenvalues $\beta_i(t)$ of the polarizability tensor are the principal axis polarizabilities.

Given a set of measurements of the target response with varying geometries or "look angles" at the target, the data can be inverted to determine the local (X,Y,Z) location of the target, the orientation of its principal axes (ϕ,θ,ψ), and the principal axis polarizabilities $(\beta_1,\beta_2,\beta_3)$. The basic idea is to search out the set of nine parameters $(X,Y,Z,\phi,\theta,\psi,\beta_1,\beta_2,\beta_3)$ that minimizes the difference between the measured responses and those calculated using the dipole response model. Since the system currently does not know or record the location or orientation of the cart, target location and orientation are known well locally but not well geo-referenced.

For TEMTADS data, inversion is accomplished by a two-stage method. In the first stage, the target's (X,Y,Z) dipole location beneath is solved for non-linearly. At each iteration within this inversion, the nine element polarizability tensor ($\mathbf{B}$) is solved linearly. We require that this tensor be symmetric; therefore, only six elements are unique. Initial guesses for X and Y are determined by a signal-weighted mean. The routine normally loops over a number of initial guesses in Z, keeping the result giving the best fit as measured by the chi-squared value. The non-linear inversion is done simultaneously over all time gates, such that the dipole (X,Y,Z) location applies to all decay times. At each time gate, the eigenvalues and angles are extracted from the polarizability tensor.

In the second stage, six parameters are used: the three spatial parameters (X,Y,Z) and three angles representing the yaw, pitch, and roll of the target (Euler angles ϕ,θ,ψ). Here the eigenvalues of the polarizability tensor are solved for linearly within the 6-parameter non-linear inversion. In this second stage both the target location and its orientation are required to remain constant over all time gates. The value of the best fit X,Y,Z from the first stage, and the median value of the first-stage angles are used as an initial guess for this stage. Additional loops over depth and angles are included to better ensure finding the global minimum.

Figure 6-1 shows an example of the principal axis polarizabilities determined from TEMTADS array data. The target, a mortar fragment, is a slightly bent plate about 0.5 cm thick, 25 cm long, and 15 cm wide. The red curve is the polarizability when the primary field is normal to the surface of the plate, while the green and blue curves correspond to cases where the primary field is aligned along each of the edges.

Not every target on the target list exhibited a strong enough TEM response to support extraction of target polarizabilities. All of the data were run through the inversion routines, and the results manually screened to identify those targets that could not be reliably parameterized. Several criteria were used: signal strength relative to background, dipole fit error (difference between data and model fit to data), and the visual appearance of the polarizability curves.

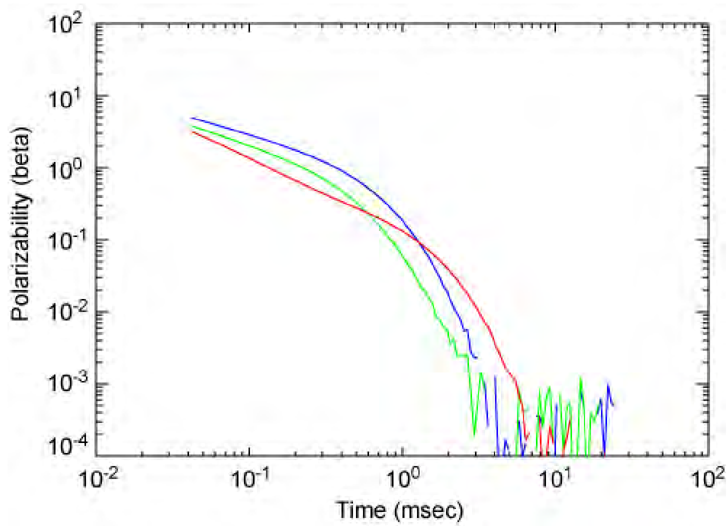

Figure 6-1 – Principal axis polarizabilities for a 0.5 cm thick by 25 cm long by 15 cm wide mortar fragment.

6.3 DATA PRODUCT SPECIFICATIONS

See Appendix C for the detailed data product specifications.

7.0 PERFORMANCE ASSESSMENT

The performance objectives for this demonstration are summarized in Table 3-1 and are repeated here as Table 7-1. The results for each criterion are subsequently discussed in the following sections.

Table 7-1 – Performance Results for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria	Success? (Yes/No)
Quantitative Performance Objectives				
Site Coverage	Fraction of assigned anomalies interrogated	Survey results	100% as allowed for by topography / vegetation	Yes
IVS Results	System responds consistently to emplaced items	Daily IVS data	≤ 15% RMS variation in β amplitudes and fit depth	Yes
Depth Accuracy	Standard deviation in depth for interrogated items	Ground truth from validation effort	ΔDepth < 5 cm σDepth < 10 cm	TBD
Production Rate	# of anomalies investigated each day	• Survey results • Log of field work	Average of 125 anomalies/day	Yes
Data Throughput	Throughput of data QC process	Log of analysis work	All data QC'ed on site and at pace with survey	Yes
Qualitative Performance Objective				
Reliability and Robustness	General Observations	Team feedback and recording of emergent problems	Field team has no issues to report	Yes

7.1 OBJECTIVE: SITE COVERAGE

A list of 913 previously identified anomalies was provided by the Program Office. The expectation was to gather cued data with the TEMTADS MP 2x2 Cart over each anomaly.

7.1.1 Metric

Site coverage is defined as the fraction of the anomalies that was surveyed by the TEMTADS MP 2x2 Cart. Exceptions were made for topography / vegetation interferences.

7.1.2 Data Requirements

The collected data were compared to the original anomaly list. Any interferences (*e.g.,* a misidentified cultural item such as a fence post) were noted in the field log book as they were observed by the field team.

7.1.3 Success Criteria

The objective is considered met if 100% of the assigned anomalies were surveyed with the exception of anomalies that cannot be accessed due to topology / vegetation interferences.

7.1.4 Results

This objective was successfully met. Of the list provided by the Program Office, all were measured. After demobilization, an issue was identified with target 841 by another survey team. It appeared that the pin flag had been moved 4m North from its recorded location at some unknown time.

7.2 OBJECTIVE: INSTRUMENT VERIFICATION STRIP RESULTS

This objective supports that the sensor system is in good working order and collecting physically valid data each day. The items emplaced in the IVS were surveyed twice daily. The amplitude of the derived response coefficients and fit depth for each emplaced item were compared to the running average of the demonstration for repeatability. If a corresponding reference response was available in our library, the quality of the match was evaluated as well.

7.2.1 Metric

The reproducibility of the measured response of the sensor system to the emplaced items defines this metric.

7.2.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients and fitted depth. If available, a reference set of derived response coefficients for the same object was used.

7.2.3 Success Criteria

The objective is considered met if the RMS amplitude variation of the derived response coefficients and fitted depths was less than 15% of the average recovered response coefficients.

7.2.4 Results

As discussed in Section 5.4.3, the β coefficient amplitude RMS variations were well under 15%, with a peak of 8.3% for the smallest transverse βs. The RMS variations in the fitted depths were less than 7% for all items.

7.3 OBJECTIVE: DEPTH ACCURACY

An important measure of how efficiently any required intrusive investigation will proceed is the accuracy of the predicted depth of the targets marked to be dug. Large depth errors lead to confusion among the UXO technicians assigned to the effort costing time and often lead to the removal of a small, shallow object when a larger, deeper object was the intended target.

7.3.1 Metric

The average offset and standard deviation of the predicted depths with respect to the ground truth are computed for the items which are selected for excavation during the validation phase of the study.

7.3.2 Data Requirements

The anomaly fit parameters and the ground truth for the excavated items are required to determine the performance of the fitting routines in terms of the predicted depth accuracy.

7.3.3 Success Criteria

This objective is considered as met if the average error in depth (ΔDepth) was less than 5 cm and the standard deviation (σDepth) was less than 10 cm.

7.3.4 Results

The ground truth is not currently available. The success of this objective will be evaluated at a later time.

7.4 OBJECTIVE: PRODUCTION RATE

This objective considers a major cost driver for the collection of high-density, high-quality geophysical data, the production rate. Increased data collection rates translate to fewer days needed on-site for the data collection effort.

7.4.1 Metric

This objective is considered met if the number of anomalies investigated per day met or exceeded the success criteria listed below without sacrificing data quality or compromising personnel health and safety. Note that this metric does not distinguish between regular data collection and necessary recollections, or redos. On any geophysical survey, there is going to be a necessary level of redo data collections and these should be planned for.

7.4.2 Data Requirements

The metric was determined from the combination of the field logs and the survey results. The field logs record the amount of time per day spent acquiring the data and the survey results determine the number of anomalies investigated in that time period.

7.4.3 Success Criteria

This objective is considered met if the average production rate was at least 125 anomalies/day. This metric is site-specific and was based on our previous experience with this site and the sensor system. The success criteria may vary at other sites based on site-specific conditions.

7.4.4 Results

This objective was successfully met. The crew averaged 173 anomalies / day for 5.5 days of active data collection, excluding calibration strip data collection. On the best day, June 10th, data were collected for 204 anomalies. The CH2M HILL data collection crew was being trained in the use of the sensor in real time, indicating that this pace should be sustainable over time.

7.5 OBJECTIVE: DATA THROUGHPUT

The collection of a complete, high-quality data set with the sensor platform is critical to the downstream success of the Live Site Demonstrations. This objective considers one of the key data quality issues, the ability of the data analysis workflow to support the data collection effort in a timely fashion. To maximize the efficient collection of high quality data, a series of standard data quality checks were conducted during and immediately after data collection on site. Data which passed the QC screen were then processed into archival data stores. Individual anomaly analyses were then conducted on those archival data stores. The data QC / preprocessing portion of the workflow must keep pace with the data collection effort for best performance.

7.5.1 Metric

The throughput of the data quality control workflow was at least as fast as the data collection process, providing real time feedback to the data collection team of any emergent issues.

7.5.2 Data Requirements

The data analysts log books provide the necessary data for determining the success of this metric.

7.5.3 Success Criteria

This objective is considered met if all collected data were processed through the data quality control portion of the workflow in a timely fashion.

7.5.4 Results

This Objective was successful. Data throughput kept pace with data collection for the entire demonstration. The CH2M HILL data analyst was trained onsite by the SAIC data analyst from a cold start on the first day of the demonstration and was able to keep up throughout the demonstration.

7.6 OBJECTIVE: RELIABILITY AND ROBUSTNESS

This objective represents an opportunity for all parties involved in the data collection process to provide feedback on areas where the process could be improved.

7.6.1 Data Requirements

Discussions with the entire field team and other observations were used.

7.6.2 Results

This objective was successful. As this demonstration was a cooperative effort with CH2M HILL in technology transfer, the majority of the data collection and data preprocessing / QC was conducted by CH2M HILL staff with training and assistance from NRL and SAIC. At the completion of the demonstration, the CH2M HILL staff was asked for any feedback / suggestions to improve the system / process. The team was generally pleased with the system and had no major recommendations for improvement.

This demonstration was the first live site demonstration of the new cart. This was also the first demonstration with new, smaller wheels designed to reduce the ride height of the platform. The height of the cart handle was found to be 2-4 cm too low for general comfort. The handle height will be revised prior to the next demonstration. The tread (rubber) of the new wheels was found to not be solidly anchored to the plastic wheel and could be forced off the wheel at extreme angles. The tread will be glued to the wheels in the future. The increased size and weight of the electronics package to accommodate the receiver cubes has changed the weight and balance of the backpack. Based on field team feedback, the arrangement of the equipment on the backpack can be improved. This will be investigated further.

8.0 COST ASSESSMENT

The cost elements that were tracked for this demonstration are detailed in Table 8-1. The provided cost elements are based on a three-person field crew (2 data collection and 1 data analyst). The TEMTADS MP 2x2 Cart is not a commercially available system, but an estimated daily rental rate is provided for comparison to other technologies. The rental rate is based, in part, on the costs of items purchased in prototype quantities (single units) and would presumably decrease significantly if the items were procured at production quantity levels. As this demonstration was a cooperative effort between CH2M HILL, SAIC, and NRL, a second cost table (Table 8-2) is provided including costs for two quarter-time advisors to train the CH2M HILL team on the operation of the TEMTADS MP 2x2 Cart and the processing of the collected data. Therefore, the costs in Table 8-2 are more reflective of the actual costs of this demonstration, as performed.

Table 8-1 – Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	$5,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$12,450 1 16 3 8 $7,250
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$520 2 2
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$15.30 / anom.** $285 1 2 8 0.5
Processing Costs		**$10.85 / anom.**
Preprocessing	Time required to perform standard data clean up and to merge the location and geophysical data.	3 min/anomaly
Parameter Estimation	Time required to extract parameters for all anomalies.	2 min/anomaly

Table 8-2 – Tracked Costs Including Training Personnel

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	$5,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$16,500 1 16 5 8 $8,750
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$620 2.25 2
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$17.95 / anom.** $285 1 2.25 8 0.5
Processing Costs		**$14.35 / anom.**
Preprocessing	Time required to perform standard data clean up and to merge the location and geophysical data.	3 min/anomaly
Parameter Estimation	Time required to extract parameters for all anomalies.	2 min/anomaly

9.0 SCHEDULE OF ACTIVITIES

Figure 9-1 gives the overall schedule for the demonstration including deliverables.

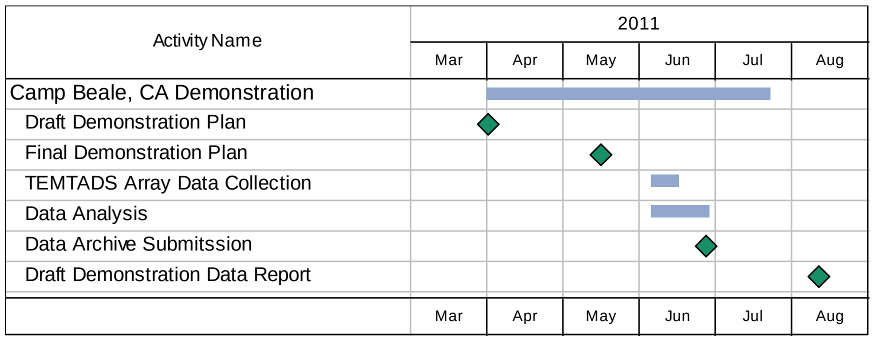

Figure 9-1 – Schedule of all demonstration activities including deliverables.

10.0 MANAGEMENT AND STAFFING

The responsibilities for this demonstration are outlined in Figure 10-1. Dan Steinhurst is the PI of this demonstration. Dan Steinhurst filled the roles of Site / Project Supervisor. Dean Keiswetter and Tamir Klaff served as the SAIC Project Manager and CH2M HILL Project Leads, respectively. Tom Bell served as Quality Assurance Officer. Glenn Harbaugh was the Site Safety Officer. His duties included data collection and safety oversight for the entire team. Jim Kingdon and Andrew Gascho served as the Data Analysts. Matthew Barner and Andrew Louder served as Data Acquisition Operators.

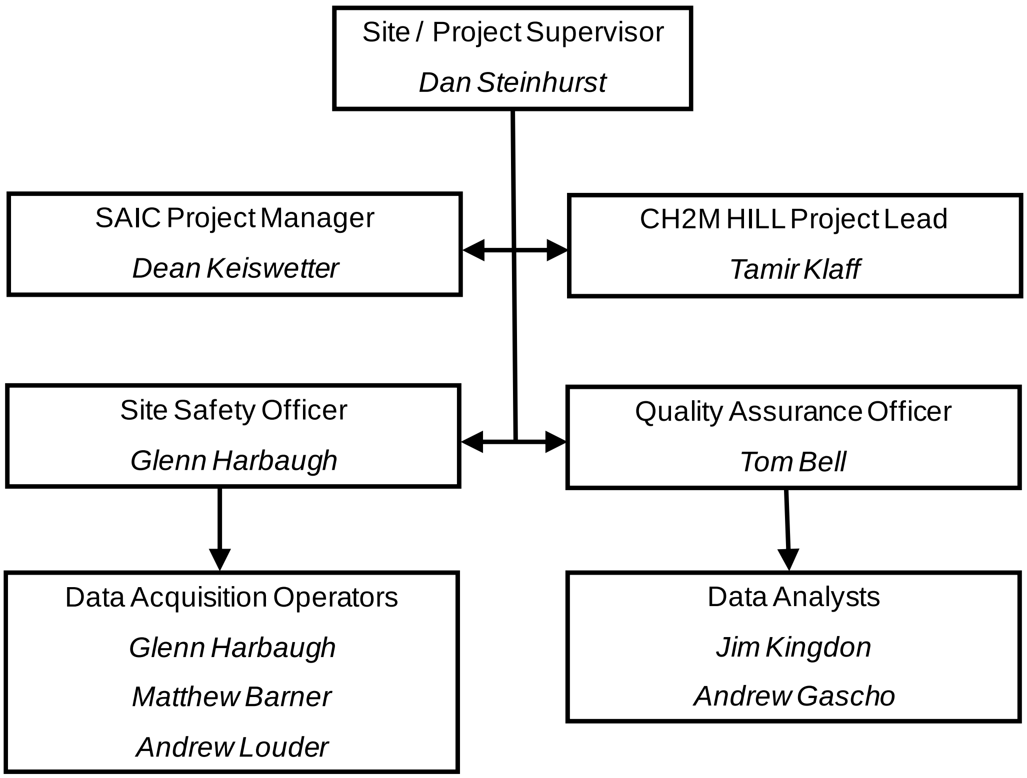

Figure 10-1 – Management and Staffing Wiring Diagram.

11.0 REFERENCES

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12. Bell, T. H., Barrow, B. J., and Miller, J. T., "Subsurface Discrimination Using Electromagnetic Induction Sensors," IEEE Transactions on Geoscience and Remote Sensing, Vol. 39, No. 6, June 2001.

APPENDIX A. HEALTH AND SAFETY PLAN (HASP)

The Health and Safety Plan for our previous demonstration on the same site was used for this demonstration[1]. All emergency information such as contact numbers and directions to nearby medical facilities are provided in that document.

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1 "EM61 MkII Transect Demonstration at Former Camp Beale, Technology Demonstration Plan," accepted by ESTCP Program Office on May 3, 2007.

APPENDIX B. POINTS OF CONTACT

POINT OF CONTACT	ORGANIZATION	Phone Fax e-mail	Role in Project
Dr. Jeff Marqusee	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-2120 (V) 703-696-2114 (F) jeffrey.marqusee@osd.mil	Director, ESTCP
Dr. Anne Andrews	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-3826 (V) 703-696-2114 (F) anne.andrews@osd.mil	Deputy Director, ESTCP
Dr. Herb Nelson	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203	703-696-8726 (V) 703-696-2114 (F) 202-215-4844 (C) herbert.nelson@osd.mil	Program Manger, MR
Ms. Katherine Kaye	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	410-884-4447 (V) kkaye@hgl.com	Program Manager Assistant, MR
Mr. Daniel Reudy	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	703-736-4531 (V) druedy@hgl.com	Program Manager's Assistant, MR
Dr. Dan Steinhurst	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	202-767-3556 (V) 202-404-8119 (F) 703-850-5217 (C) dan.steinhurst@nrl.navy.mil	PI
Mr. Glenn Harbaugh	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	804-761-5904 (V) glenn.harbaugh.ctr@nrl.navy.mil	Site Safety Officer
Dr. Tom Bell	SAIC 4001 N. Fairfax Drive – 4th Floor Arlington, VA 22203	(703)-312-6288 (V) thomas.h.bell@saic.com	Quality Assurance Officer
Dr. Dean Keiswetter	SAIC 120 Quade Drive Cary, NC 27513	(919) 677-1560 (V) dean.a.keiswetter@saic.com	SAIC Project Manager
Mr. Tamir Klaff	CH2M HILL	(202) 596-199 (V) Tamir.klaff@CH2M.com	CH2M HILL Project Lead

APPENDIX C. DATA FORMATS

C.1 TEM DATA FILE (*.TEM)

These data files are a binary format generated by a custom .NET serialization routine. They are converted to an ASCII, comma-delimited format in batches as required. Each file contains 4 data points, corresponding to each Tx cycle. Each data point contains the Tx transient and the corresponding 12 Rx transients as a function of time. A pair of header lines is also provided for, one overall file header and one header per data point with the data acquisition parameters. A partial example is provided below.

Line 1 - File Header

```
CPUms,PtNo,LineNo,Delt,BlockT,nRepeats,DtyCyc,nStk,AcqMode,GateWid,Gate
HOff,TxSeq,GateT,TxI_Z,Rx0Z_TxZ,Rx0Y_TxZ,Rx0X_TxZ,Rx1Z_TxZ,Rx1Y_TxZ,Rx1
X_TxZ,Rx2Z_TxZ,Rx2Y_TxZ,Rx2X_TxZ,Rx3Z_TxZ,Rx3Y_TxZ,Rx3X_TxZ,
```

Line 2 - Data Point Header

```
0,1,0,2E-06,0.9,9,0.5,18,2,0.05,5E-05,10,

0            - Start time in ms on CPU clock (always 0)
1            - Data Point Number (always 1)
0            - Line Number (always 0)
2E-06        - Time step for transients (seconds)
0.9          - Base period length (seconds)
9            - Number of Tx cycles in a base period
0.5          - Duty cycle
3            - Number of base periods averaged (or stacked)
2            - Data Acquisition Mode (binned)
0.05         - Gate width as fraction of its own time
5E-05        - Hold-off time (seconds) for first data point
10           - Tx ID number (sensor number + 10)
```

Line 3 - First Data Line in First Data Point

```
,,,,,,,,,,,,2.5E-05,2.60167412880684,-0.00465650176945326,-
0.000793715251683923,0.0014301131016373,-0.00156031010951301,-
0.000206528327198378,-0.00181886894811034,-
0.000755585606977845,0.00172118642304864,-0.00090539694841071,-
0.000716199742511644,0.0023067225488303,0.000269091967209883,
```

C.2 LEVELED DATA FILE

Prior to any analysis of the .TEM data files, the data are background-subtracted and normalized for transmitter power. These leveled data sets are also provided in a .CSV format. The self-explanatory header row and one line of data are provided below.

```
Tx #, Time(ms), Tx Current, Rx 0z, Rx 0y, Rx 0x, Rx 1z, Rx 1y, Rx 1x,
Rx 2z, Rx 2y, Rx 2x, Rx 3z, Rx 3y, Rx 3x
 0,8.900e-002,5.367,  -31.89873,   -6.64546,   18.41490,  -38.48213,   -
6.28577,   -34.86225,   -10.46400,     18.56384,   -23.98543,   -17.33803,
17.15812,   7.71650
,
```